



# CDMA-Based DCP Communications System

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# DCP CDMA-Overlay Overview

- CDMA overview
- CDMA-overlay concept
  - Overview
  - Capacity results
- CDMA-only concept
  - Overview
  - Capacity results
- Considerations in applying CDMA to DCS
- Summary



# CDMA Overview

- CDMA users transmit spread spectrum signal at the same time using all of the available bandwidth
  - Each user assigned a unique code so that the receiver can separate out a particular user's signal
  - Codes have low cross correlation for separation
    - Wideband signals interfere with each other
- Managed Resource
  - Power compared to frequency (FDMA) or time (TDMA)
  - CDMA capacity maximized when the SINRs of the users are all equal and minimum for a desired BER
- “Soft degradation” with increasing number of users
  - CDMA: Supported based on tolerable amount of interference
    - If BER of  $10^{-5}$  is acceptable compared to  $10^{-6}$  → Capacity increase
- CDMA Presence
  - Terrestrial cellular migrating to CDMA (IS95 → IS2000 , GSM → WCDMA)
  - Conceptual design for Globalstar based on CDMA



# CDMA Overview (con't)

- Asynchronous CDMA vs Synchronous CDMA
  - Synchronous requires signals be aligned in time but better capacity
    - Signal alignment is at the chip level: Clocks need to be accurate on microsecond scale, path delays need to be known to the microsecond level, etc.
    - Cellular uses synchronous on the links from base station to mobile (1→many) channel
  - Asynchronous does not require signals to be aligned in time but worse capacity
    - Cellular uses asynchronous on the links from mobile to base station (many→1) channel
- Spreading Sequences or “Codes”
  - Long random codes
    - Capacity interference limited (ie: as  $C/N_0 \rightarrow \infty$ , capacity still finite)
    - Requires more granular synchronization
  - Short codes
    - Capacity Interference limited
    - No synchronization required
  - Orthogonal codes
    - Capacity not interference limited
    - Limited Applicability



# CDMA Overview: Application to DCS System

- CDMA DCP system is a many→1 communications channel
  - Multiple DCPs transmit to single CDA
- Two development paths
  - Use of orthogonal codes (**Probably Not Practical for DCS**)
    - Capacity follows Shannon limit
    - Users to do not interfere
    - Requires that DCP signal arrive at the CDA code-aligned in time
      - Requires that DCP know delay through entire communications chain to an accuracy of approximately 10-20us
      - Continuous updating needed to account for satellite drift as satellite drift could result in more than 20us of change in delay
      - Continuous updating implies a closed loop timing system which requires DCPs receive information from CDA to update timing
      - Any doppler / multipath in propagation environment reduces degree of orthogonality of codes. Multiple propagation paths (1 per DCP) complicates problem.
  - **Neither Globalstar nor terrestrial Cellular systems use orthogonal codes on many→1 channels**
- Use of non orthogonal codes (**More Practical for DCS**)
  - Capacity becomes interference limited which is less than Shannon limit
  - Power control critical as capacity is maximized when power levels of signals received at the CDA all equal
    - Unequal signal powers reduces capacity significantly



# DCP CDMA-Overlay Concept

- Overlay a CDMA-based DCP uplink onto the current 400KHz of spectrum used for the existing DCPR system
- Assign unique random codes to the individual CDMA-overlay DCPs
- CDMA-overlay DCPs transmit a 400KHz direct sequence spread spectrum (DSSS) signal simultaneously
  - Results in interference to both CDMA and FDMA DCPs
  - Goal is to ensure interference levels are tolerable for both
  - Interference well modeled as AWGN
- CDMA Receiver demodulates DSSS signals for each CDMA-based DCP
- Power levels need to be managed
  - Excessive powers (link margin) for the desired BER results in unnecessary interference
- Admission control
  - Optimal (maximize capacity) implementation should be based on current interference levels

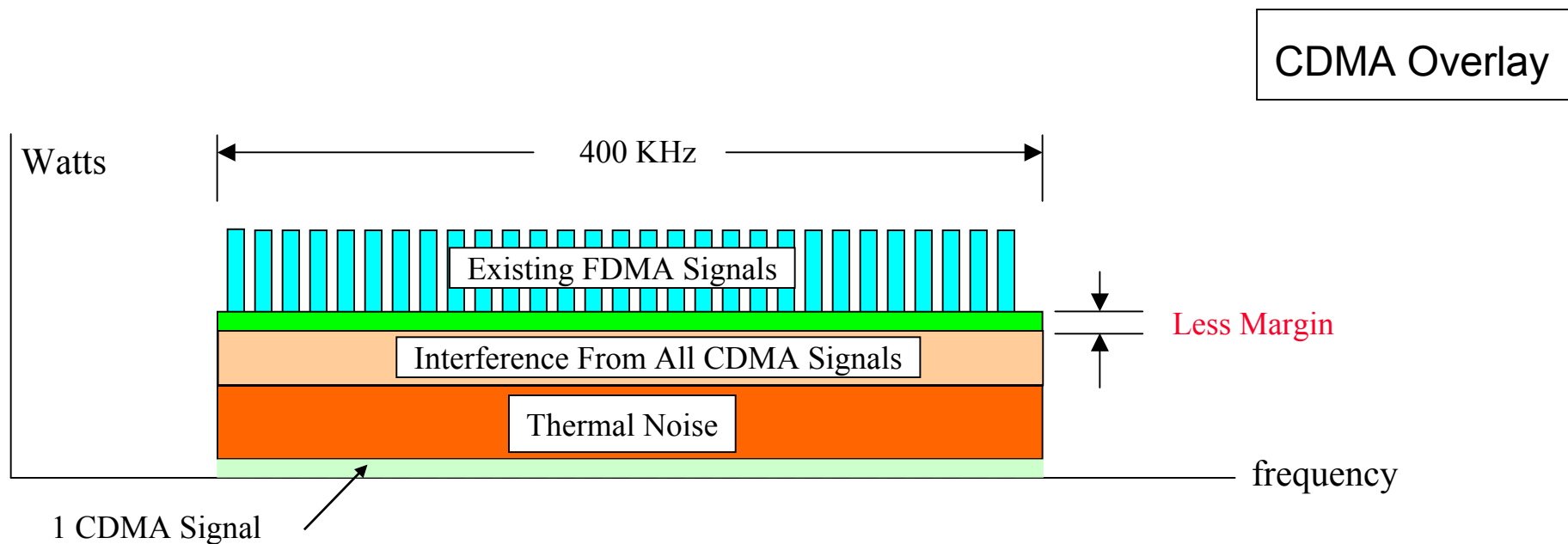
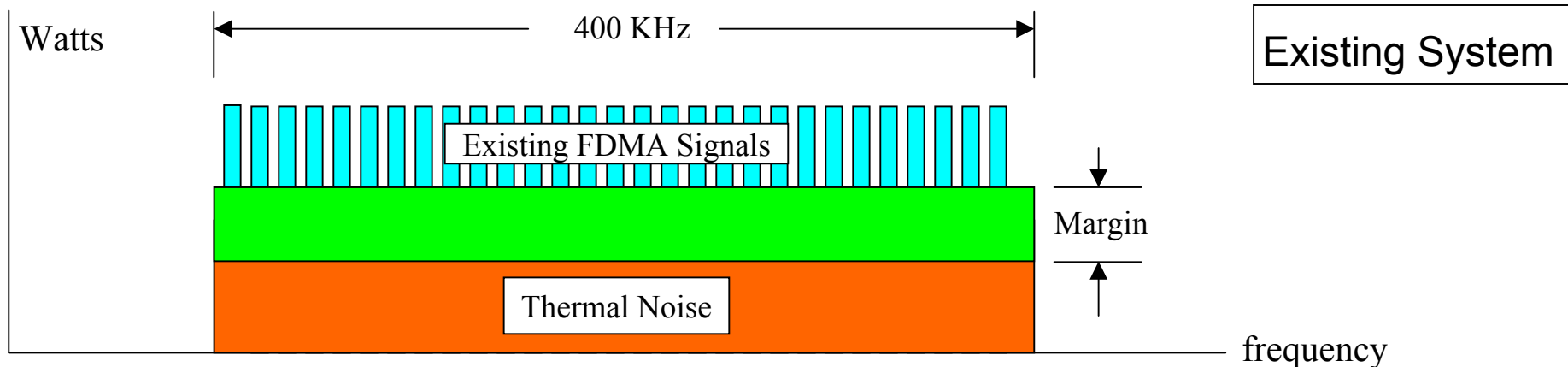


# DCP CDMA-Overlay Concept

- CDMA-overlay signals coexist with existing FDMA system without any change to system
  - Useful to support low frequency unscheduled transmissions such as emergency transmissions
  - CDMA-overlay transmitters provided to DCPs that may require emergency transmissions
  - All emergency transmission dissemination sites equipped with CDMA receivers
- CDMA-overlay transmitters exist as separate units ( wrt existing FDMA transmitter)
  - Share same antenna and possibly PA
- CDMA-overlay receivers exist as separate units
  - Share same antenna
  - Possibly share same RF front-end
  - Baseband signal processing component exists as separate unit



# DCS Spectrum





# Power Control

- Ideal power control would result in all CDMA-overlay receive powers being equal and minimum to support desired BER performance level
- Power control error reduces capacity
- Three approaches to power control
  - No power control
    - Receive power differences  $\sim 6$  dB (terrestrial cellular as high as 50 – 75 dB)
      - Path loss, channel (rain, ionospheric affects), antenna gain, specification allows for difference in transmit power
  - Open loop power control
    - CDMA-overlay DCPs measure receive power from DCPI link
    - Transmit power based on measured receive power
    - Account for path loss differences and channel
    - Differences in receive power with open loop power control  $\sim 3$  dB
  - Closed loop power control
    - DCPI link used to send up/down commands to CDMA-overlay DCPs
    - Differences in receive power with open loop power control  $\sim 2$  dB
- Closed loop power control best but most complex to implement



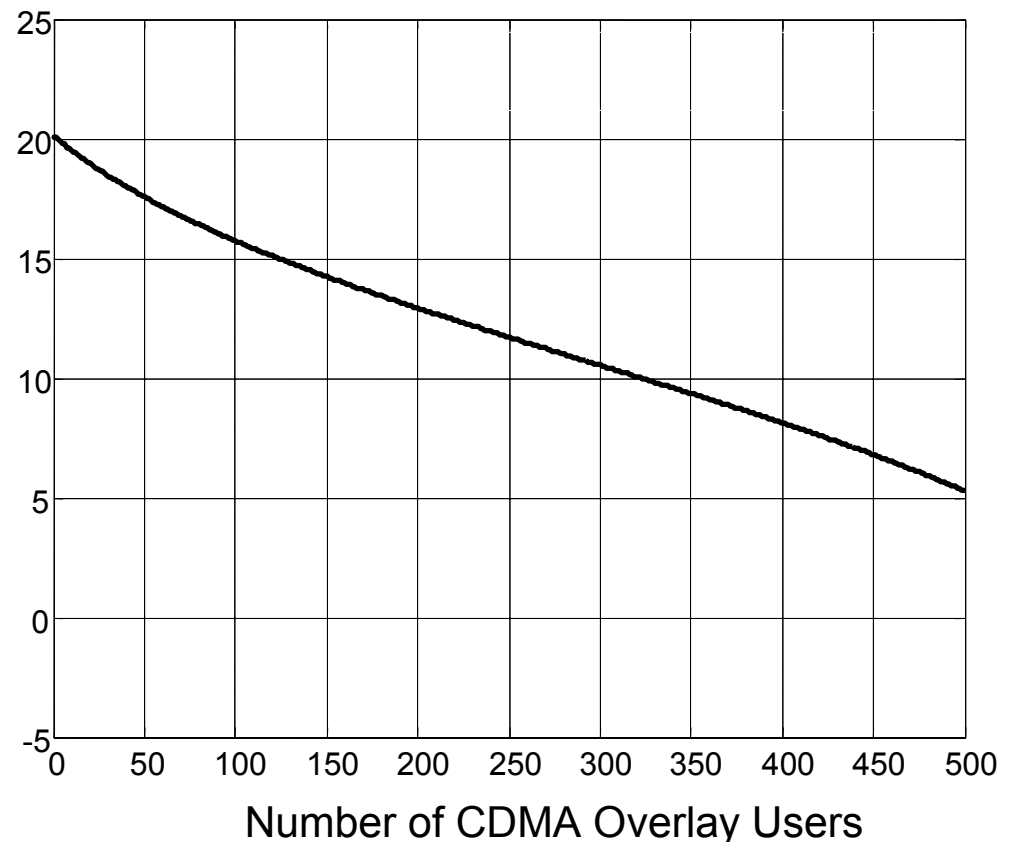
# CDMA Signal Reduces Existing FDMA DCP $E_B/N_0$

- CDMA overlay capacity is limited by the amount of interference CDMA users will introduce to narrowband FDMA users
- Plot shows how Existing FDMA DCP  $E_B/N_0$  decreases as a function of overlay users

Illustrates  $E_B/N_0 \downarrow$  as  
CDMA-overlay users  $\uparrow$

Existing FDMA  
DCP  $E_B/N_0$

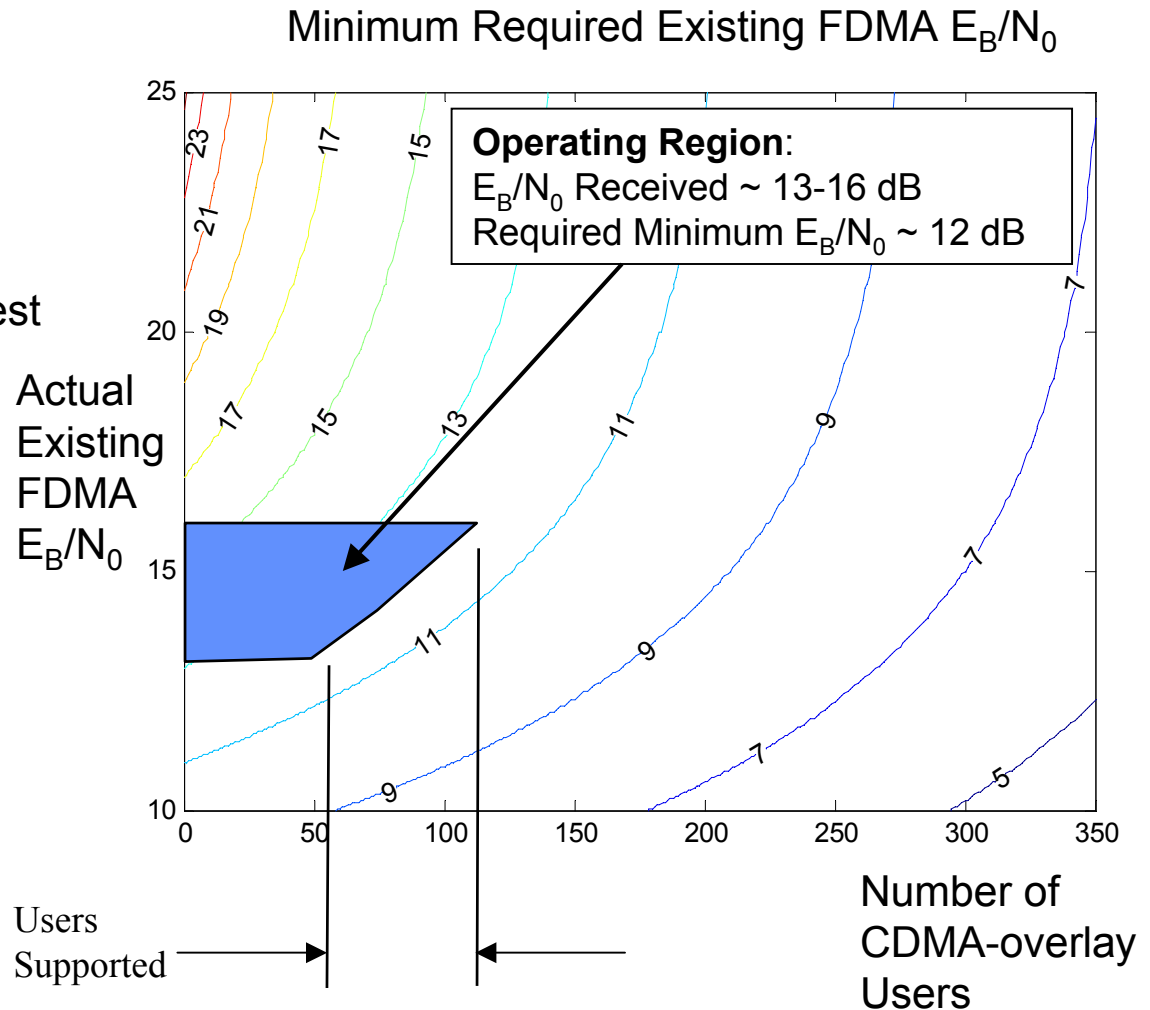
CDMA Interference Impact to Existing FDMA DCPs





# Theoretical CDMA-Overlay Capacity

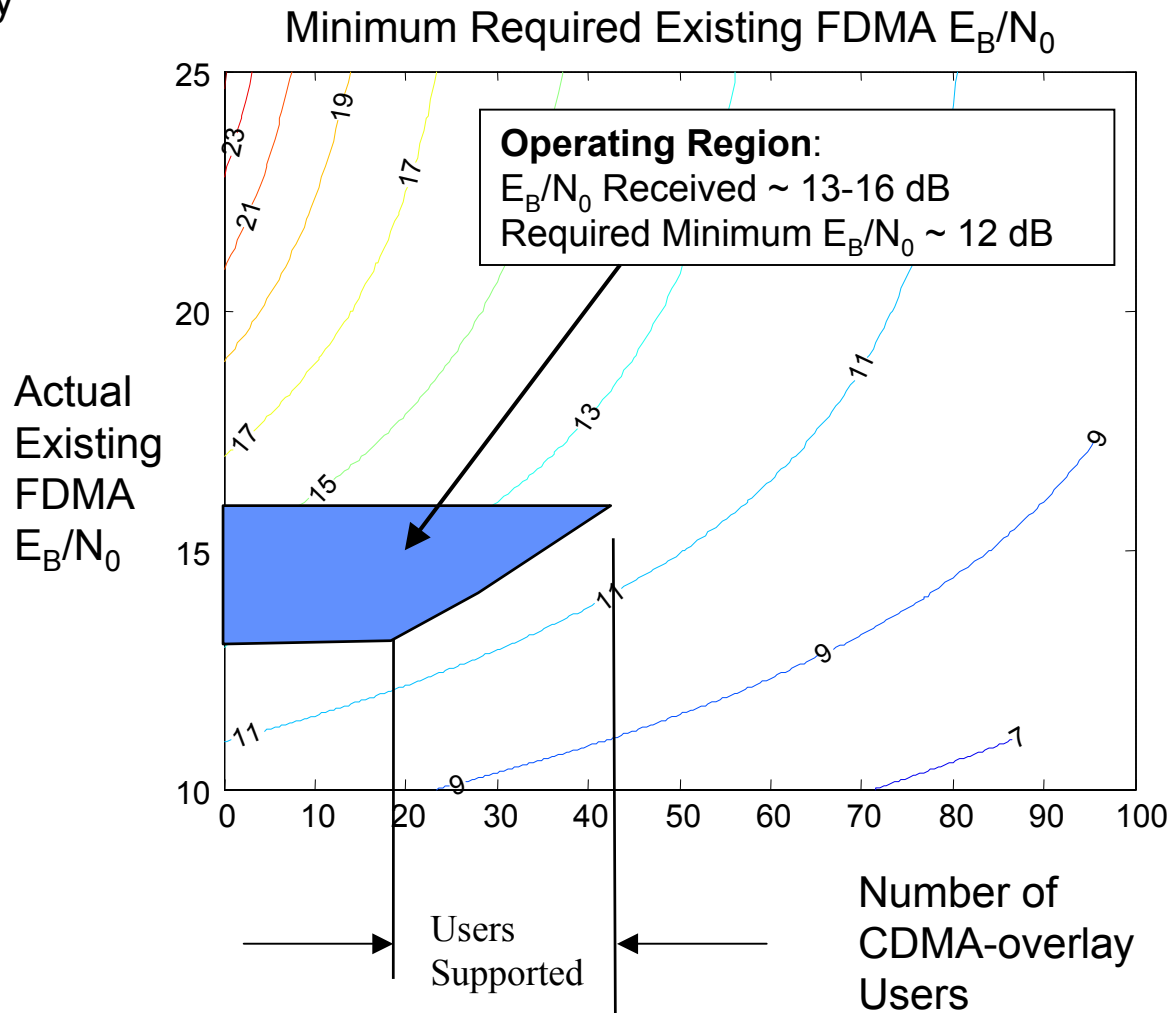
- CDMA-overlay Capacity
  - Perfect power control
  - Ideal Receiver
- Assume typical DCPR operating  $E_B/N_0 \sim 13\text{-}16$  dB
- Further minimum  $E_B/N_0 \sim 12$  dB
  - Based on empirical DCPR test results
- Number of users  $\sim 50$  to  $110$





# Practical CDMA-Overlay Capacity

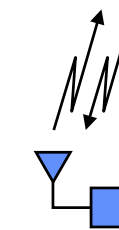
- Non Ideal CDMA-overlay Capacity
  - CDMA DCPs receive powers vary by 6 dB
    - Receive powers neither equal nor minimum
- Number of users ~ 20 to 45



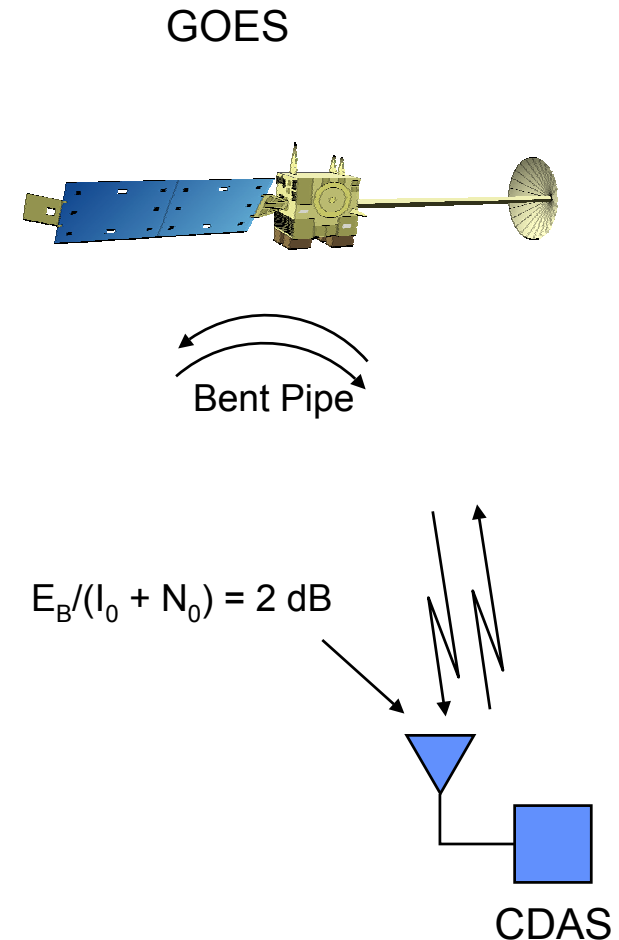


# CDMA-Only High Level Concept

- Uplink (Link from DCP to CDAS)
  - New 400 KHz bandwidth frequency assignment
  - Use CDMA only
  - Design to support ~ 400-450 simultaneous channels (300 BPS)
    - Data and a few control channels
  - Asynchronous
    - User signals not aligned in time
  - BPSK data modulation
- Downlink (Link from CDAS to DCP)
  - New 40 KHz bandwidth frequency assignment
  - Use CDMA only
  - Design to support 32 simultaneous channels (300 BPS)
    - Power control + control channels
  - Synchronous
    - Signals aligned in time
    - Allows use of orthogonal codes
    - QPSK data modulation

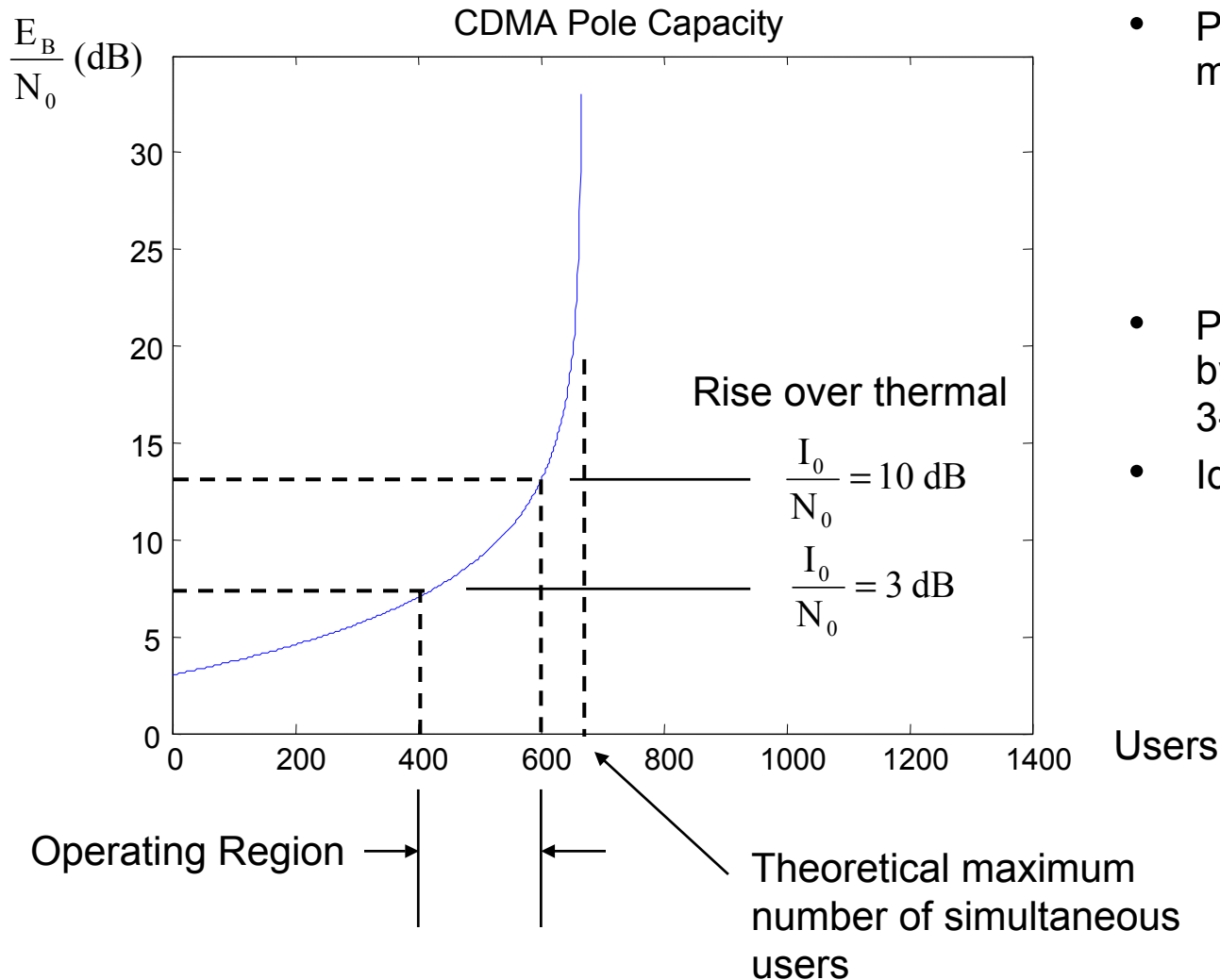


DCPs





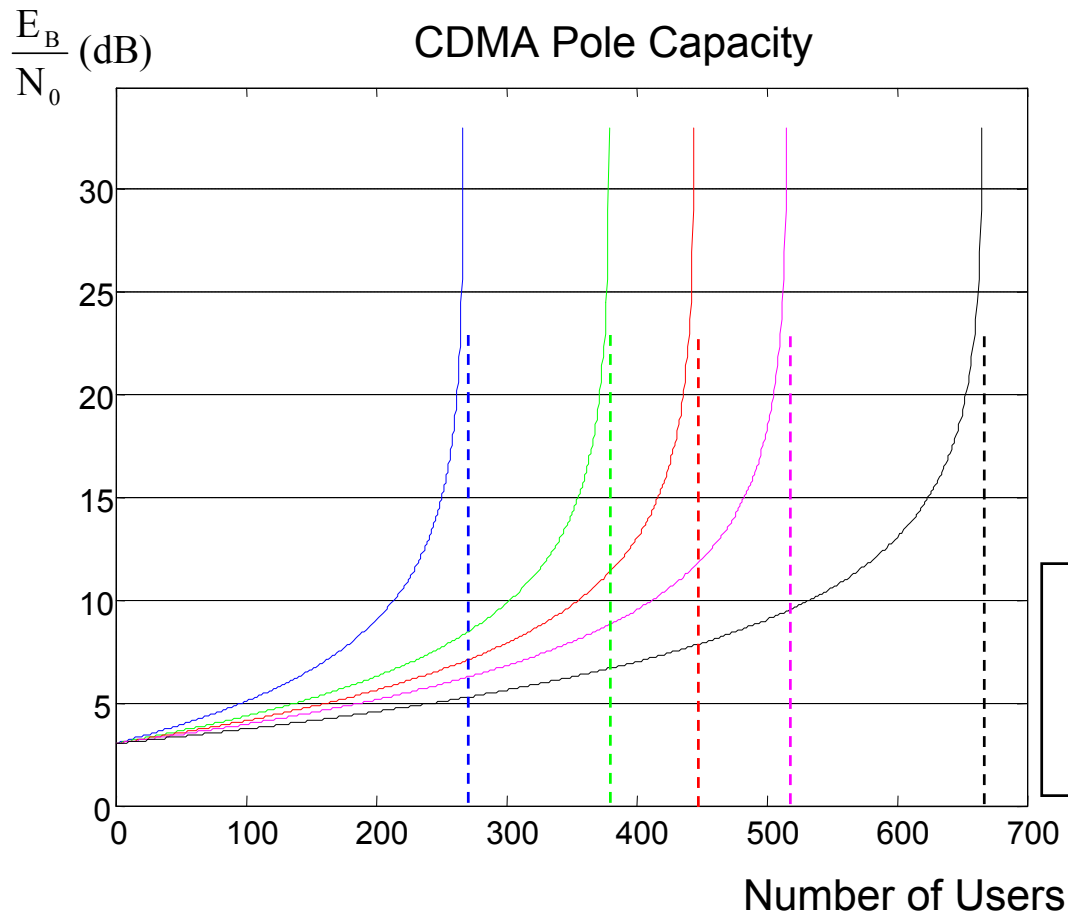
# CDMA “Pole Capacity”



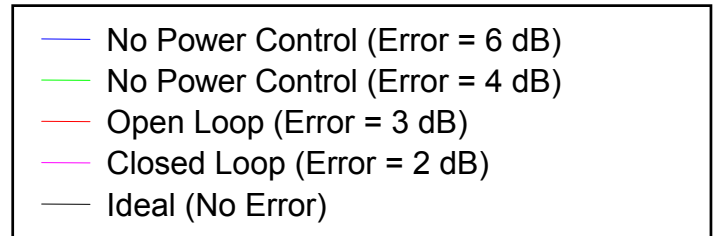
- Pole capacity: Theoretical maximum number of users
  - Pole capacity attained when  $E_B/N_0 \rightarrow \infty$
  - Curve assumes random codes
- Practical operating range given by “rise over thermal” between 3-10 dB
- Ideal receiver
  - Impairments due to noise + interference only



# Impact of Power Control



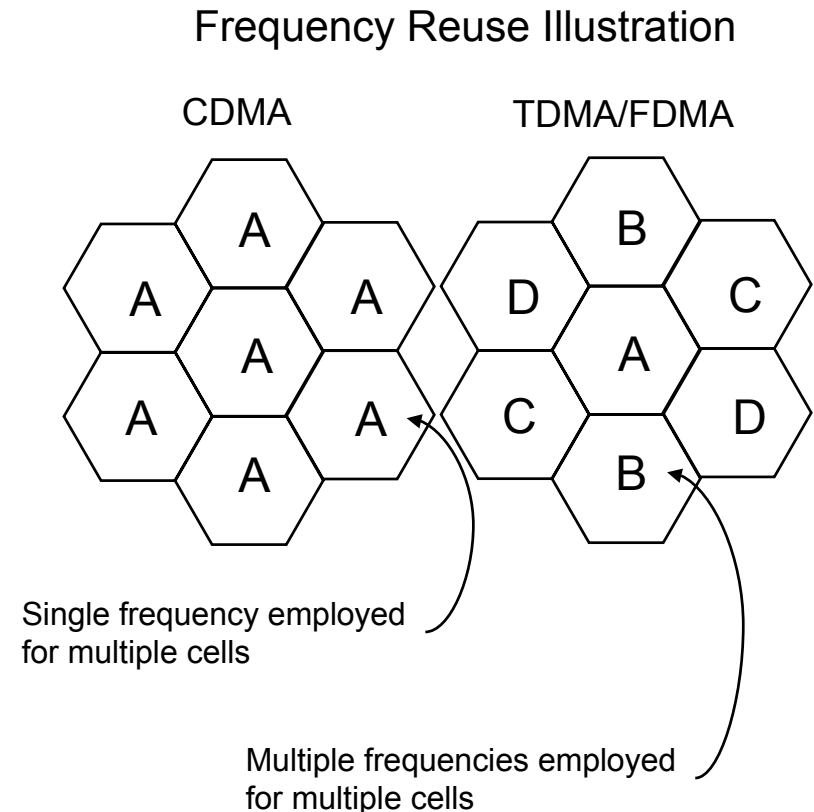
- Pole capacity decreases with inability to control power
- Power control error = power received beyond what is necessary to sustain desired BER





# Why has the Cellular Community adopted CDMA?

- Better suited for multipath fading channels
  - Additional paths “combined” to result in path diversity
  - FDMA/TDMA, additional paths not able to be combined and results in link degradation
- Better suited when omni antennas employed
- Better suited for cellular networks (terrestrial) or spot-beam (satellite) applications
  - Universal frequency reuse: CDMA reuses same frequencies in adjacent cells (unlike TDMA/FDMA)
  - Soft Handoff gains
- Resistant to narrowband interference
  - CDMA inherently spread spectrum
- Inactivity Gain
  - Inactivity (such as pauses in speech) can be translated to capacity gain. This is not possible with FDMA and difficult with TDMA.





# CDMA Challenges for DCP

- General Purpose COTS COTS Chipset Availability
  - Want to use commercial chipsets as custom development of chipsets costly
    - CDMA signals require much digital/signal processing resulting in complex ICs
    - Existing chipsets are commercially available but designed specifically for IS2000 or WCDMA which probably wouldn't be appropriate for a DCS CDMA system
      - Chip rates different, Chip sets assume maximum difference in path delay between transmitting units < 250 km, etc
- CDMA systems are more complex
  - Power control
  - Admission control
- CDMA-only system is a complete redesign/overhaul of existing system
- CDMA-overlay represents additional hardware to CDA and new transmitters for CDMA-overlay DCPs but existing system remains



# DCS CDMA Summary

- CDMA-only DCS system
  - Number of simultaneous users comparable to simpler FDMA system
  - CDMA system significantly more complex and would require essentially a complete redesign of current DCS system
- CDMA-Overlay DCS system
  - May be an effective scheme to support a low number of non-scheduled additional messages
    - No change to satellite required
    - No change to operating practices to support ~ 20 CDMA-overlay users
    - Used for emergency channels, etc.